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THE EFFECT OF THE ENERGY COST OF INSULATION AND STORM WINDOWS AND DOORS ON THE DECISION TO INSTALL THEM AS AN ENERGY SAVING POLICY

By

Anthony Sebald

April 1975

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THE EFFECT OF THE ENERGY COST OF INSULATION AND STORM WINDOWS AND DOORS ON THE DECISION TO INSTALL THEM AS AN ENERGY SAVING POLICY

by

Anthony Sebald

Energy Research Group
Center for Advanced Computation
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April 1975

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1.0 Introduction

The purpose of this report is to investigate the energy tradeoffs inherent in the fabrication and installation of home insulation. In particular, the net energy savings, defined as the difference between energy saved due to insulation and the energy cost to fabricate and install it, are evaluated as a function of heating degree days and seasonal air conditioning hours. The effects of five different thicknesses of ceiling insulation and the presence or absence of storm windows and doors are investigated.

Calculations are based on a 1200 sq. ft. "standard" house, and the use of different fuels (oil, natural gas, and electricity) is discussed. Payback periods for each of these categories (ie the time required for energy savings to equal energy costs) are also presented.

Finally, several "worst case" examples are carried out:

(1) The effect of adding only storm windows and doors to a house.

(2) The effect of adding 3 additional inches of ceiling insulation to a house which has 3 inches already installed.

From the outset we must emphasize that we are investigating only the energy tradeoffs, ie can energy be saved by adding insulation given that its fabrication requires energy. The dual questions of whether money can be saved and what is the economically optimal level of insulation have been answered by various other studies.[1,2 3,12]

2.0 Methodology

2.1 The Model Home

All of the results in this document are based on the following model home:

Floor Area:	1200 ft^2 (assume 30 ft x 40 ft)
Windows:	Double hung wood North 60 ft^2 South 75 ft^2 East 25 ft^2 West 35 ft^2
Exterior Walls:	1/2 in x 8 in. lapped wood siding 25/32 in. insulated board sheathing 3 5/8 in. air space 1/2 in. gypsum wall board
Ceiling:	3/8 in. gypsum board
Roof:	Asphalt shingles Building paper 25/32 in. wood sheathing
Attic:	Natural ventilation (0.1 cfm / ft^2)
Floor:	3/4 in. hardwood floor Felt 25/32 in. wood subfloor

We shall investigate the effects of adding the following:

(i) Aluminum combination storm windows and doors

(ii) Ceiling insulation of the following thicknesses:

1 1/2 in., 2 in., 3 in., 5 in., 6 in.

2.2 The Energy Cost of Storm Windows and Insulation

An Input-Output model[4] has been developed to determine the energy cost in Btu per dollar of purchases in the U.S. economy. The model divides the economy into 357 sectors and calculates energy intensities (Btu per $)

for each sector. In general, one obtains the energy cost of a commodity by multiplying the energy intensity (Btu per $) of the sector to which the commodity belongs by the equivalent price of the commodity in the base model year. The latest available model is for the year 1967, so dollar prices must be quoted in 1967 dollars. We therefore assume that the energy cost, in Btu, of insulation and storm windows/doors has not varied significantly since 1967. Although the exact error resulting from this assumption is unknown, it is not believed to be very large. While it is true that the dollar costs have fluctuated wildly due to inflation etc., the number of barrels of oil or tons of coal required to fabricate these items has not changed nearly so drastically. Details of the actual calculations are given in Appendix A.

2.3 Energy Savings for Both Heating and Air Conditioning

Heat load or the quantity of Btu per heating season required to maintain the interior of a residence at a comfortable temperature (eg 70°) may be evaluated by repeated use of the simple formula:[3]

$$\text{load} = \text{area } (\text{ft}^2) \times U \left(\frac{\text{Btu}}{\text{hr-°F-ft}^2} \right) \times \text{HDD} \left(\frac{\text{°F-days}}{\text{season}} \right) \times 24 \left(\frac{\text{hrs}}{\text{day}} \right)$$

for each section of the house with distinct insulating properties. The total heat load then equals the sum of the individual loads. The values of U are obtained from tables in [3]. Details are given in Appendix B.

Due to the difference in mechanisms involved, cooling loads are theoretically very different than corresponding heat loads. In fact, residential cooling loads are best evaluated with the use of empirical tables.[3] Annual cooling load evaluation essentially involves multiplying the average annual air conditioning hours for the location of the house[*] by the sum of the hourly cooling losses for each thermally different part of the house. Although the latter are tabulated as a function of temperature parameters which depend on the geographical location of the house, it is possible to derive a constant approximation which is valid for the continental U.S. After evaluating the total hourly cooling load for the standard house located in various cities,* we find a total variation of only ± 10 percent about a nominal value. Since factors like window orientation and roof color have relatively large influence on heat entry and since the technique is empirical by nature, the overall accuracy of the result is not seriously compromised by the use of the nominal hourly cooling load.

---

[*] Obtained from Chapter 17, Table 2, reference [5].

---

*Minneapolis, Chicago, St. Louis, New York, Washington, D.C., New Orleans, Houston, Miami.

3.0 Results

In this section, we present the general results regarding net annual energy savings and payback times as a function of fuel type, degree of insulation and heating/cooling season intensity. We also work several examples to illuminate the question of marginal paybacks (ie. if the house is already partially insulated, does it pay to add more?) and, finally, an example showing use of the results for a homeowner in Chicago will be worked out.

3.1 Net Energy Savings and Payback Period for the Heating Season

The annual net energy savings (ANS) are defined by the following equation:

$$\text{ANS} = (\text{NONINS} - \text{INS}) \times \frac{\text{HDD}}{\text{EFF}} - \frac{\text{BTUCOST}}{20} \tag{3-1}$$

where NONINS = The heat loss of the house in millions of Btu per heating degree day (HDD) assuming the presence of neither insulation nor storms.

INS = The heat loss of the house in millions of Btu per HDD assuming a particular configuration of insulation and storms.

EFF = The combined fuel and heating system efficiency.*

BTUCOST = The total energy cost in millions of Btu of the particular configuration of insulation and storms.

20 = The assumed lifetime, in years, of the insulation and/or storms.

Figures 3.1 a, b, and c give the net annual energy savings with natural gas, oil and electricity as respective fuels. Each table gives savings in millions of Btu for all six insulation types as a function of the number of

---

*See Table B-3 of Appendix B.

Table 3.1a

GAS USED AS FUEL

NET ENERGY SAVINGS BY INSULATION TYPE (Millions of Btu per year) - Heating

	HEATING DEGREE DAYS PER YEAR									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
INSULATION THICKNESS = 0.0 INCHES.										
INSULATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSULATION + STORMS	4.48	11.61	18.73	25.86	32.98	40.11	47.23	54.35	61.48	68.60
INSULATION THICKNESS = 1.5 INCHES.										
INSULATION	8.44	17.11	25.79	34.47	43.15	51.83	60.51	69.19	77.87	86.55
INSULATION + STORMS	12.92	28.72	44.53	60.33	76.13	91.94	107.74	123.55	139.35	155.15
INSULATION THICKNESS = 2.0 INCHES.										
INSULATION	9.23	18.79	28.34	37.90	47.45	57.01	66.57	76.12	85.68	95.23
INSULATION + STORMS	13.71	30.39	47.07	63.75	80.43	97.12	113.80	130.48	147.16	163.84
INSULATION THICKNESS = 3.0 INCHES.										
INSULATION	10.20	20.82	31.43	42.04	52.65	63.26	73.88	84.49	95.10	105.71
INSULATION + STORMS	14.69	32.42	50.16	67.90	85.63	103.37	121.11	138.84	156.58	174.31
INSULATION THICKNESS = 5.0 INCHES.										
INSULATION	11.09	22.75	34.41	46.07	57.73	69.40	81.06	92.72	104.38	116.04
INSULATION + STORMS	15.57	34.36	53.14	71.93	90.72	109.50	128.29	147.07	165.86	184.64
INSULATION THICKNESS = 6.0 INCHES.										
INSULATION	11.32	23.28	35.25	47.22	59.19	71.15	83.12	95.09	107.05	119.02
INSULATION + STORMS	15.80	34.89	53.98	73.07	92.17	111.26	130.35	149.44	168.53	187.62

Table 3.1b

OIL USED AS FUEL

NET ENERGY SAVINGS BY INSULATION TYPE (millions of Btu per year) - Heating

	HEATING DEGREE DAYS PER YEAR									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
INSULATION THICKNESS = 0.0 INCHES.										
INSULATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSULATION + STORMS	4.68	11.99	19.31	26.63	33.94	41.26	48.58	55.89	63.21	70.53
INSULATION THICKNESS = 1.5 INCHES.										
INSULATION	8.67	17.58	26.50	35.41	44.33	53.24	62.16	71.07	79.98	88.90
INSULATION + STORMS	13.35	29.58	45.81	62.04	78.27	94.50	110.73	126.96	143.19	159.43
INSULATION THICKNESS = 2.0 INCHES.										
INSULATION	9.49	19.30	29.12	38.93	48.75	58.56	68.37	78.19	88.00	97.82
INSULATION + STORMS	14.17	31.30	48.43	65.56	82.69	99.82	116.95	134.08	151.21	168.34
INSULATION THICKNESS = 3.0 INCHES.										
INSULATION	10.49	21.39	32.29	43.19	54.09	64.98	75.88	86.78	97.68	108.58
INSULATION + STORMS	15.17	33.38	51.60	69.81	88.03	106.25	124.46	142.68	160.89	179.11
INSULATION THICKNESS = 5.0 INCHES.										
INSULATION	11.41	23.38	35.36	47.33	59.31	71.29	83.26	95.24	107.21	119.19
INSULATION + STORMS	16.08	35.38	54.67	73.96	93.25	112.55	131.84	151.13	170.43	189.72
INSULATION THICKNESS = 6.0 INCHES.										
INSULATION	11.64	23.93	36.22	48.51	60.80	73.09	85.38	97.67	109.97	122.26
INSULATION + STORMS	16.32	35.92	55.53	75.14	94.75	114.35	133.96	153.57	173.18	192.78

Table 3.1c

ELECTRICITY USED AS FUEL

NET ENERGY SAVINGS BY INSULATION TYPE (Millions of Btu per year) - Heating

	HEATING DEGREE DAYS PER YEAR									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
INSULATION THICKNESS = 0.0 INCHES.										
INSULATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSULATION + STORMS	14.86	32.36	49.86	67.36	84.86	102.35	119.85	137.35	154.85	172.35
INSULATION THICKNESS = 1.5 INCHES.										
INSULATION	21.08	42.39	63.71	85.03	106.35	127.67	148.99	170.31	191.63	212.95
INSULATION + STORMS	35.93	74.75	113.57	152.39	191.21	230.03	268.85	307.66	346.48	385.30
INSULATION THICKNESS = 2.0 INCHES.										
INSULATION	23.15	46.62	70.09	93.56	117.03	140.51	163.98	187.45	210.92	234.39
INSULATION + STORMS	38.01	78.98	119.95	160.92	201.89	242.86	283.83	324.80	365.77	406.74
INSULATION THICKNESS = 3.0 INCHES.										
INSULATION	25.66	51.72	77.79	103.86	129.92	155.99	182.05	208.12	234.18	260.25
INSULATION + STORMS	40.52	84.08	127.65	171.21	214.78	258.34	301.91	345.47	389.04	432.60
INSULATION THICKNESS = 5.0 INCHES.										
INSULATION	28.07	56.71	85.36	114.00	142.64	171.28	199.93	228.57	257.21	285.85
INSULATION + STORMS	42.93	89.07	135.21	181.36	227.50	273.64	319.78	365.92	412.06	458.20
INSULATION THICKNESS = 6.0 INCHES.										
INSULATION	28.74	58.14	87.53	116.93	146.32	175.72	205.11	234.51	263.91	293.30
INSULATION + STORMS	43.60	90.50	137.39	184.29	231.18	278.07	324.97	371.86	418.76	465.65

heating degree days in the season. For each insulation thickness and heating degree day level, the savings with respect to the uninsulated house due to adding just insulation and both insulation and storms is given. Therefore, the annual energy savings due to adding 3 inches of insulation and storm windows to an uninsulated house with oil heat in a city averaging 3000 HDD are (from Table 3-1b) 51.60 million Btu. Finally, it can be seen from a simple algebraic manipulation of equation (3-1) that the marginal net savings increase from one insulation/storm scenario to another (eg. adding 3 more inches of insulation) is simply the difference between their annual net savings (taken from Tables 3-1a, b, or c). Perhaps a more important way of analyzing the energy tradeoffs is to answer how long it would take, given a fuel type, a number of HDD and some insulation/storm scenario to accrue enough savings to "pay" the entire energy cost of the scenario. Using the same format as Table 3-1, Tables 3-2a, b, and c, give the ratio of yearly annual energy saved to total energy cost for each insulation/storm scenario. Adding six inches of ceiling insulation and storm windows to an uninsulated house having electric heat and experiencing 5000 HDD per season would, according to Table 3-2c, be repaid 3.56 times in the first year. Unfortunately, marginal paybacks of adding additional amounts of insulation cannot always be obtained from Table 3-2. Instead, we shall work two examples.

Example 3.1 What is the payback period for adding storm windows and doors to an already insulated house?

This example can be solved using Table 3-2. Regardless of the insulation level of the house, the heat loss through the windows will depend solely on the presence or absence of storms. We can, therefore, use the payback period for storms without insulation given in Tables 3-2a, b and c. For

Table 3.2a

GAS USED AS FUEL

Ratio of Annual Energy Savings to Total Energy Cost - Heating

	HEATING DEGREE DAYS PER YEAR									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
INSULATION THICKNESS = 0.0 INCHES.										
INSULATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSULATION + STORMS	0.13	0.27	0.40	0.54	0.67	0.81	0.94	1.08	1.21	1.35
INSULATION THICKNESS = 1.5 INCHES.										
INSULATION	1.77	3.55	5.32	7.10	8.87	10.65	12.42	14.20	15.97	17.75
INSULATION + STORMS	0.27	0.55	0.82	1.10	1.37	1.64	1.92	2.19	2.47	2.74
INSULATION THICKNESS = 2.0 INCHES.										
INSULATION	1.47	2.93	4.40	5.86	7.33	8.80	10.26	11.73	13.19	14.66
INSULATION + STORMS	0.28	0.56	0.84	1.12	1.41	1.69	1.97	2.25	2.53	2.81
INSULATION THICKNESS = 3.0 INCHES.										
INSULATION	1.30	2.60	3.91	5.21	6.51	7.81	9.12	10.42	11.72	13.02
INSULATION + STORMS	0.29	0.58	0.87	1.16	1.46	1.75	2.04	2.33	2.62	2.91
INSULATION THICKNESS = 5.0 INCHES.										
INSULATION	1.02	2.04	3.07	4.09	5.11	6.13	7.16	8.18	9.20	10.22
INSULATION + STORMS	0.29	0.59	0.88	1.17	1.46	1.76	2.05	2.34	2.63	2.93
INSULATION THICKNESS = 6.0 INCHES.										
INSULATION	0.92	1.84	2.75	3.67	4.59	5.51	6.43	7.34	8.26	9.18
INSULATION + STORMS	0.29	0.58	0.87	1.16	1.45	1.74	2.03	2.32	2.61	2.90

Table 3.2b

OIL USED AS FUEL

Ratio of Annual Energy Savings to Total Energy Cost - Heating

	HEATING DEGREE DAYS PER YEAR									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
INSULATION THICKNESS = 0.0 INCHES.										
INSULATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSULATION + STORMS	0.14	0.28	0.42	0.55	0.69	0.83	0.97	1.11	1.25	1.39
INSULATION THICKNESS = 1.5 INCHES.										
INSULATION	1.82	3.65	5.47	7.29	9.11	10.94	12.76	14.58	16.41	18.23
INSULATION + STORMS	0.28	0.56	0.84	1.13	1.41	1.69	1.97	2.25	2.53	2.81
INSULATION THICKNESS = 2.0 INCHES.										
INSULATION	1.51	3.01	4.52	6.02	7.53	9.03	10.54	12.05	13.55	15.06
INSULATION + STORMS	0.29	0.58	0.87	1.16	1.44	1.73	2.02	2.31	2.60	2.89
INSULATION THICKNESS = 3.0 INCHES.										
INSULATION	1.34	2.68	4.01	5.35	6.69	8.03	9.36	10.70	12.04	13.38
INSULATION + STORMS	0.30	0.60	0.90	1.20	1.49	1.79	2.09	2.39	2.69	2.99
INSULATION THICKNESS = 5.0 INCHES.										
INSULATION	1.05	2.10	3.15	4.20	5.25	6.30	7.35	8.40	9.45	10.50
INSULATION + STORMS	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00
INSULATION THICKNESS = 6.0 INCHES.										
INSULATION	0.94	1.89	2.83	3.77	4.71	5.66	6.60	7.54	8.48	9.43
INSULATION + STORMS	0.30	0.60	0.89	1.19	1.49	1.79	2.08	2.38	2.68	2.98

Table 3.2c

ELECTRICITY USED AS FUEL

Ratio of Annual Energy Savings to Total Energy Cost - Heating

	HEATING DEGREE DAYS PER YEAR									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
INSULATION THICKNESS = 0.0 INCHES.										
INSULATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSULATION + STORMS	0.33	0.66	0.99	1.33	1.66	1.99	2.32	2.65	2.98	3.31
INSULATION THICKNESS = 1.5 INCHES.										
INSULATION	4.36	8.72	13.08	17.44	21.80	26.16	30.52	34.88	39.24	43.60
INSULATION + STORMS	0.67	1.35	2.02	2.69	3.36	4.04	4.71	5.38	6.06	6.73
INSULATION THICKNESS = 2.0 INCHES.										
INSULATION	3.60	7.20	10.80	14.40	18.01	21.61	25.21	28.81	32.41	36.01
INSULATION + STORMS	0.69	1.38	2.07	2.76	3.45	4.14	4.83	5.53	6.22	6.91
INSULATION THICKNESS = 3.0 INCHES.										
INSULATION	3.20	6.40	9.60	12.80	16.00	19.19	22.39	25.59	28.79	31.99
INSULATION + STORMS	0.71	1.43	2.14	2.86	3.57	4.29	5.00	5.72	6.43	7.15
INSULATION THICKNESS = 5.0 INCHES.										
INSULATION	2.51	5.02	7.53	10.04	12.55	15.06	17.58	20.09	22.60	25.11
INSULATION + STORMS	0.72	1.44	2.16	2.87	3.59	4.31	5.03	5.75	6.47	7.19
INSULATION THICKNESS = 6.0 INCHES.										
INSULATION	2.25	4.51	6.76	9.02	11.27	13.53	15.78	18.04	20.29	22.55
INSULATION + STORMS	0.71	1.42	2.14	2.85	3.56	4.27	4.99	5.70	6.41	7.12

natural gas, oil and electric heat respectively, including efficiencies, storms will be repaid 1.35, 1.39 and 3.31 times in 10,000 HDD.

Example 3.2 Given a house with 3 inches of ceiling insulation, what is the payback period for an additional 3 inches?

From Table 3-5, the decrease in energy consumption per HDD resulting from a change from 3 to 6 inches of ceiling insulation is (excluding efficiencies)

$$20.5 - 19.6 = .9 \text{ thousand Btu per HDD}$$

From Table A-1 of Appendix A, the energy cost of 3 inches of insulation is 8.148 million Btu.

The payback time excluding efficiencies is then given by

$$\frac{900 \ \text{Btu/HDD}}{8.148 \text{ million Btu}} = 1.104 \text{ times per } 10{,}000 \text{ HDD}$$

The inclusion of heating system efficiencies decreases the payback time to 1.708, 1.755 and 4.198 times per 10,000 HDD for natural gas, oil and electric heat respectively.

3.2 Net Energy Savings and Payback Period for the Air Conditioning Season

The results here are completely analogous to those of the previous section. The annual net energy savings (in millions of Btu per cooling season hour (CSH)) are given in Table 3-3. The payback periods are given in Table 3-4. Only electricity was considered as an air conditioner fuel. As seen in Table 3-3, the addition of 6 inches of ceiling insulation and storm windows and doors to a house in a region of 800 CSH per year save 19.11 million Btu per year (assuming a 20-year life on the insulation and storms). As seen in

Table 3.3

ELECTRICITY USED AS FUEL

NET ENERGY SAVINGS BY INSULATION TYPE (millions of Btu per year) - Air conditioning

	COOLING SEASON HRS PER YEAR 200	400	600	800	1000	1200	1400	1600	1800	2000
INSULATION THICKNESS = 0.0 INCHES.										
INSULATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSULATION + STORMS	-1.85	-1.07	-0.28	0.51	1.30	2.08	2.87	3.66	4.45	5.23
INSULATION THICKNESS = 1.5 INCHES.										
INSULATION	3.06	6.36	9.66	12.96	16.26	19.56	22.87	26.17	29.47	32.77
INSULATION + STORMS	1.20	5.29	9.38	13.47	17.56	21.65	25.74	29.83	33.91	38.00
INSULATION THICKNESS = 2.0 INCHES.										
INSULATION	3.38	7.08	10.79	14.49	18.20	21.90	25.61	29.31	33.02	36.73
INSULATION + STORMS	1.53	6.02	10.51	15.00	19.50	23.99	28.48	32.97	37.47	41.96
INSULATION THICKNESS = 3.0 INCHES.										
INSULATION	3.79	7.98	12.18	16.37	20.57	24.76	28.96	33.16	37.35	41.55
INSULATION + STORMS	1.94	6.92	11.90	16.88	21.87	26.85	31.83	36.81	41.80	46.78
INSULATION THICKNESS = 5.0 INCHES.										
INSULATION	4.12	8.82	13.52	18.21	22.91	27.60	32.30	36.99	41.69	46.38
INSULATION + STORMS	2.27	7.75	13.24	18.72	24.20	29.68	35.17	40.65	46.13	51.61
INSULATION THICKNESS = 6.0 INCHES.										
INSULATION	4.16	8.97	13.79	18.60	23.41	28.22	33.04	37.65	42.66	47.47
INSULATION + STORMS	2.31	7.91	13.51	19.11	24.71	30.31	35.91	41.51	47.11	52.71

Table 3.4

ELECTRICITY USED AS FUEL

Ratio of Annual Energy Savings to Total Energy Cost - Air conditioning

	COOLING SEASON HRS PER YEAR									
	200	400	600	800	1000	1200	1400	1600	1800	2000
INSULATION THICKNESS = 0.0 INCHES.										
INSULATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSULATION + STORMS	0.01	0.03	0.04	0.06	0.07	0.09	0.10	0.12	0.13	0.15
INSULATION THICKNESS = 1.5 INCHES.										
INSULATION	0.68	1.35	2.03	2.70	3.38	4.05	4.73	5.40	6.08	6.75
INSULATION + STORMS	0.07	0.14	0.21	0.28	0.35	0.43	0.50	0.57	0.64	0.71
INSULATION THICKNESS = 2.0 INCHES.										
INSULATION	0.57	1.14	1.71	2.27	2.84	3.41	3.98	4.55	5.12	5.68
INSULATION + STORMS	0.08	0.15	0.23	0.30	0.38	0.45	0.53	0.61	0.68	0.76
INSULATION THICKNESS = 3.0 INCHES.										
INSULATION	0.51	1.03	1.54	2.06	2.57	3.09	3.60	4.12	4.63	5.15
INSULATION + STORMS	0.08	0.16	0.25	0.33	0.41	0.49	0.57	0.65	0.74	0.82
INSULATION THICKNESS = 5.0 INCHES.										
INSULATION	0.41	0.82	1.23	1.65	2.06	2.47	2.88	3.29	3.70	4.12
INSULATION + STORMS	0.09	0.17	0.26	0.34	0.43	0.51	0.60	0.68	0.77	0.85
INSULATION THICKNESS = 6.0 INCHES.										
INSULATION	0.37	0.74	1.11	1.48	1.85	2.21	2.58	2.95	3.32	3.69
INSULATION + STORMS	0.09	0.17	0.26	0.34	0.43	0.51	0.60	0.68	0.77	0.85

Table 3-4, the energy cost of the 6 inches of insulation and storms will be repaid in 3 seasons.

Let us rework the two examples of the previous section to elucidate marginal paybacks due to air conditioning. In this case, they require use of energy consumption data for the various insulation and storm scenarios. Tables 3-5 and 3-6 give, respectively, heating energy consumption in 10^3 Btu/HDD and cooling energy consumption in 10^3 Btu/CSH.

Example 3.3 What is the cooling payback period for adding storm windows and doors to an already insulated house?

Here again, we can go directly to the payback table (Table 3-4). Including efficiencies, the storms will be repaid .15 times per 2,000 cooling season hours (CSH). To put this in the proper perspective, recall* that Jacksonville, Florida, experiences about 1600 CSH per season. In particular, in Jacksonville, the energy invested in these storms would require 8.33 years to recover.

Example 3.4 Given a house with 3 inches of ceiling insulation, what is the cooling payback period for an additional 3 inches?

From Table 3-6, the decrease in energy consumption per CSH resulting from a change from 3 to 6 inches of ceiling insulation is (excluding efficiencies) 1400 Btu/CSH.

From Table A-1 of Appendix A, 3 inches of ceiling insulation cost 8.148 million Btu.

---

*Table C-2 of Appendix C.

Table 3-5

Energy Consumption Per Heating Degree Day (HDD)
(Thousands of Btu Per HDD)

	House Only		Including Overall System Efficiency*	
Insulation Thickness	Insulation Only	Storms and Insulation	Insulation Only	Storms and Insulation
Natural Gas				
0	27.4	22.8	42.4	35.2
1 1/2	21.8	17.2	33.7	26.6
2	21.2	16.6	32.8	25.7
3	20.5	15.9	31.8	24.6
5	19.8	15.2	30.7	23.6
6	19.6	15.0	30.4	23.3
Fuel Oil				
0	27.4	22.8	43.5	36.2
1 1/2	21.8	17.2	34.6	27.3
2	21.2	16.6	33.7	26.4
3	20.5	15.9	32.6	25.3
5	19.8	15.2	31.5	24.2
6	19.6	15.0	31.2	23.9
Electricity				
0	27.4	22.8	104.1	86.6
1 1/2	21.8	17.2	82.8	65.3
2	21.2	16.6	80.6	63.1
3	20.5	15.9	78.0	60.5
5	19.8	15.2	75.4	58.0
6	19.6	15.0	74.7	57.2

---

*Including both the efficiency of extraction of the fuel and the heating system efficiency. For more details, see Appendix B: Especially Table B-3.

Table 3-6

Energy Consumption Per Cooling Season Hour (CSH)
(Thousands of Btu Per CSH)

	House Only		Including Overall A/C System Efficiency*	
Insulation Thickness	Insulation Only	Storms and Insulation	Insulation Only	Storms and Insulation
0"	30.1	28.3	65.1	61.2
1 1/2"	22.5	20.6	48.6	44.6
2"	21.5	19.7	46.6	42.6
3"	20.4	18.6	44.1	40.2
5"	19.2	17.4	41.6	37.7
6"	19.0	17.1	41.0	37.1

*Including the efficiency of electrical generation (.263) and the thermodynamic efficiency of the air conditioner (1.758). Note that it is possible to attain thermodynamic efficiencies greater than 1. For more details, see Appendix C.

The payback excluding efficiencies is therefore given by

$$\frac{1400\ \text{Btu/CSH}}{8.148\ \text{million Btu}} = 1.72\ \text{times per } 10{,}000\ \text{CSH.}$$

If efficiencies are included, the payback becomes 3.80 times per 10,000 CSH, which, for Jacksonville, Florida, implies a payback time of 1.64 years.

3.3 Calculation of Combined Heating and Air Conditioning Savings

Net savings can be determined by reading the appropriate net heating savings per year from Table 3-1 and adding the product of gross air conditioning savings* and cooling season hours (CSH).** Payback periods are determined by

$$\text{(3-2)} \qquad \frac{1}{\text{Cost}} \left(\text{HDD} \times \text{Heating Consumption Difference}^{\dagger} + \text{Cooling Consumption Difference}^{\dagger\dagger} \times \text{CSH} \right)$$

where: Cost = Energy cost of insulation and/or storms from Appendix A (Tables A-1 and A-2).

HDD = Number of Heating Degree Days per Season.

To illustrate, let us work a final example.

Example 3.5 Assume the model home is in Chicago, is heated with natural gas and is completely uninsulated. Calculate the combined net energy savings and payback period for both heating and air conditioning if 6 inches of ceiling insulation and storms are installed.

---

*Use the consumption including efficiency from Table 3-6.

**Table C-2 of Appendix C.

† Use the difference between consumption before and after installation (including efficiencies) from Table 3-5.

††Use the difference between consumption before and after installation (including efficiencies) from Table 3-6.

The combined net energy savings are given by

$117.18 + .028 \times 400 = 128.38$ million Btu per year.

where 117.18 are the net annual heating season savings in millions of Btu from Table 3-1a.[*]

.028 is the gross hourly cooling load saved in millions of Btu/CSH from Table 3-6.

400 is the average number of cooling hours per season in Chicago from Table C-2 of Appendix C.

To calculate payback period, we simply follow (3-2), where for the present case,

Cost $= 13.037 + 52.8 = 65.84$ million Btu.

Heating consumption difference $= 42.4 - 23.3 = 19.1$ thousand $\frac{\text{Btu}}{\text{HDD}}$

Cooling consumption difference $= 65.1 - 37.1 = 28$ thousand $\frac{\text{Btu}}{\text{CSH}}$

HDD = 6310[*]

CSH = 400 hrs/yr

The insulation and storms will therefore be repaid

$$\frac{1}{65{,}840}(19.1 \times 6310 + 28 \times 400) = 2.0 \text{ times per year.}$$

---

[*] Chicago experiences 6310 HDD per yr (reference [5], Chapter 16, Table 2).

4.0 Conclusions

1. Storm windows and doors (storms) for the standard house are much more costly in energy terms (52.8 million Btu) than even the most complete ceiling insulation scheme (6 inches cost 13 million Btu).

2. In both the heating and air conditioning cases, payback periods for storms are significantly longer than for the maximum insulation case. With respect to heating, 6 inches of insulation is paid back in approximately one seventh the time required for storms. In the air conditioning case, insulation requires only one twentieth the time for storms.

3. In general, paybacks are longer in the air conditioning case. Six inches of insulation and storms require 2350 cooling season hours (CSH) to be repaid. (Recall that New Orleans and Jacksonville, Florida, experience 1500 and 1600 CSH per year respectively.) The marginal cases are much worse. Adding an extra 3 inches of ceiling insulation to a house with 3 inches already installed requires 1.6 years for complete payback even in Jacksonville, Florida. Adding storms to an insulated house will require, even in Jacksonville, 8.3 years for complete payback.

4. Heating seasons by far require more energy and therefore pay back insulation energy investments much sooner. Six inches of insulation and storms are completely paid back in a heating season of less than 4000 HDD. Even marginal paybacks are excellent. Adding three additional inches of ceiling insulation to a house with 3 inches already installed is repaid in 2400 to 6000 HDD depending on fuel type. Even energy intensive storms when added to an insulated house are repaid in 3000 to 7500 HDD depending on fuel type.

APPENDIX A

THE ENERGY COSTS OF CEILING INSULATION AND STORM WINDOWS AND DOORS

A.1 The Energy Cost of Ceiling Insulation

Ceiling insulation of the type under consideration here is contained in Standard Industrial Classification category 3296[6] which defines Input-Output sector 3620.[7] Due to the aggregation of the economy into only 357 sectors, care must be taken to insure that the sector does not contain significant amounts of other commodities whose energy content differs strikingly from that of insulation. The primary output of the sector is defined as[6]

> "mineral wool and mineral wool insulation products made of such silicious materials as rock, slag, glass or combinations thereof."

The actual product mix for SIC category 3296* in 1967 is given in reference [8]. Three things are important here. First, mineral wool accounted for 89 percent of the total shipments (in \$) of SIC 3296. Second, the category's Primary Product Specialization Ratio** equals .92, and finally, the category' coverage ratio*** is .95.

SIC category 3296 is therefore a very homogeneous sector whose output is almost solely mineral wool. Its energy intensity (Btu/\$) will also apply equally well to fiberglass or so called rock wool since both are made by approximately the same process from an energy point of view. Reference [4] gives the 1967 energy intensity of I-O sector 3620 as 1.561 x 10^5 Btu per \$.

---

*Recall that SIC 3296 is identical to I-O sector 3620.

**The ratio of output of primary products, ie mineral wool, (\$) to primary plus secondary outputs (\$).

***The ratio of output of primary product made by SIC 3296 (\$) to the output of primary product made by all sectors (\$).

The absolute energy cost of insulation (Btu) will then be given by the product of this intensity and the unit cost in 1967 dollars. Table A-1 gives the cost per square foot of the relevant insulation options and translates that cost into absolute energy cost (Btu) for the entire house.

One final comment is in order. Strictly speaking, the energy calculation should be broken down into manufacturing energy, wholesale/retail energy and installation energy. Manufacturing is nearly a factor of 4 times as energy intensive as wholesale/retail. Installation is felt to be even less than wholesale/retail. The costs quoted in Table A-1 are materials costs to the contractor and therefore contain an unknown amount of wholesale/retail margins. The resulting energy costs are therefore conservative (ie. upper bound) even though any installation energy would tend to reduce the effect of the wholesale/retail portion being evaluated at the manufacturing energy intensity.

A.2 The Energy Cost of Storm Windows and Doors

The problem here is identical to the previous case. Storm windows and doors are included in SIC category 3442 which is identical to I-O sector 4005. The primary output of this sector is defined as:[6]

> "ferrous and nonferrous metal and metal covered
> doors and sash, window and door frames and screens,
> molding and trim."

Actual product mix for SIC 3442 in 1967 is given in reference.[8] Here again, three factors are important. First, metal doors, sash and trim of which 75% is aluminum account for 86% of the sector's total output. Second, the category's primary product specialization ratio* is .91 and

---

*As defined in the previous section.

TABLE A-1

Dollar and Btu Cost of Ceiling Insulation Options

Insulation Thickness (in.)	\$ Cost* (\$/ft^2)	Energy Cost for Entire House** (million Btu)
1 1/2	.03	4.889
2	.04	6.518
3	.05	8.148
5	.07	11.408
6	.08	13.037

---

*Cost for material only; source-reference.[9]

**Equals the product of the \$ cost x area x energy intensity. The area between rafters was estimated at 1044 ft^2 assuming rafters on 16 in. centers and a 3% safety factor.

finally, its coverage ratio* is .94. Although not quite as homogeneous as SIC 3296, this category is sufficient for our purposes. The energy intensity of this sector is[4] 1.17068×10^5 Btu/$. Total dollar and energy costs for aluminum storm windows and doors are given in Table A-2.

Some final comments are in order regarding the accuracy of these costs. Inaccuracies derive from two major causes; inhomogeneity of the category and the wholesale/retail plus application costs. In this case, the manufacturing energy intensity is somewhat understated due to the fact that the sector is a mixture of high energy aluminum and medium energy steel. This is compensated in part by the fact that the dollar cost used includes an unknown amount of wholesale/retail margins which are much less energy intensive than either steel or aluminum. Any installation energy would also tend to increase the understatement. In summary, the energy costs of Table A-2 are probably slightly understated.

---

*As defined in the previous section.

TABLE A-2

Dollar and Btu Costs for Aluminum Combination Storm Windows and Doors for the Entire Model House

	Cost ($)*	Energy Cost (million Btu)**
Storm Doors	100	11.707
Storm Windows	351	41.092
Total	451	52.800

*Source - reference.[9] There are two doors at $50 each. Two sizes of storm windows were costed in [9]. We used a 1/3 to 2/3 weighted average of the larger and smaller size respectively. Recall that the model house has 195 ft^2 of windows.

**Equals the product of $ cost x energy intensity.

APPENDIX B

HEAT LOAD CALCULATIONS

As stated in section 2.3, the seasonal (ie. annual) heat load for a given house may be calculated by summing the heat loads for each thermally distinct part of the house. Each individual load is given by

$$\text{load} = \text{area}\ (\text{ft}^2) \times U\ \left(\frac{\text{Btu}}{\text{hr-}^\circ\text{F-ft}^2}\right) \times \text{HDD}\ \left(\frac{^\circ\text{F-day}}{\text{yr}}\right) \times 24\ \left(\frac{\text{hr}}{\text{day}}\right). \tag{B-1}$$

The mechanics of the calculations are explained in several sources.[3] [5] We shall merely give our results. The first three equations will strictly follow the form of (B-1).

Walls:

$$\text{load} = 887\ \text{ft}^2 \times .19^{a} \times \text{HDD} \times 24 \tag{B-2}$$

$$= 168.53 \times \text{HDD} \times 24\ \text{Btu per yr}$$

Windows: (assume 80% glass)

Without storms:

$$\text{load} = 195\ \text{ft}^2 \times [\ .90^{b} \times 1.13^{c}\ ] \times \text{HDD} \times 24 = 198.32 \times \text{HDD} \times 24\ \text{Btu/yr} \tag{B-3}$$

With storms:

$$\text{load} = 195\ \text{ft}^2 \times [\ .90^{b} \times .56^{c}\ ] \times \text{HDD} \times 24 = 98.28 \times \text{HDD} \times 24\ \text{Btu/yr} \tag{B-4}$$

---

[a] Chapter 26, Table 4, reference [3].

[b] Chapter 26, Table 18, part C of reference [3]. This is a correction for the non-glass part of the sash.

[c] Ibid, part A. The 1.13 corresponds to flat glass and the .56 corresponds to storm windows with a 1 to 4 inch separation.

Floor: (assume a basement temperature of 50°F)

(B-5) $$\text{load} = 1200\ \text{ft}^2 \times 0.28^{d} \times \frac{75-50}{\text{Design Temp. Difference}}^{e} \times \text{HDD} \times 24$$

$$= 129.23 \times \text{HDD} \times 24\ \text{Btu/yr}$$ for a design temperature difference of 65 degrees.

Infiltration: (assume 1/2 volume air change per hr)

Here a different empirical formula[f] is used.

(B-6) $$\text{load} = 1.5^{g} \times 1200 \times 8 \times .018^{h} \times \text{HDD} \times 24$$

$$= 259.20 \times \text{HDD} \times 24\ \text{Btu/yr}$$

Ceiling: The ceiling heat loss is complicated by the attic's effect on the temperature difference across the ceiling. We follow Moyer[2] in the attic temperature calculation.

Let t_a = attic temperature (°F)

t_i = inside room temperature (°F)

t_o = outside air temperature (°F)

A_c = area of ceiling (ft^2)

A_r = area of roof (ft^2)

U_r = U value of roof (Btu per (°F) (hr) (ft^2))

---

[d] This is the U value for heat flow downward (since basement is below). Chapter 26, Table 10, reference [3].

[e] This factor is required to account for the fact that the variation in basement temperature is much less than the outside temperature variation as given by HDD.

[f] See reference [3] p. 462.

[g] Chapter 24, Table 1, reference [5]. Use 2/3 of this value if storm windows are used.

[h] Chapter 27, equation 5a, p. 461, reference [3].

U_c = U value of ceiling (Btu per (°F) (hr) (ft^2))

V = Ventilation (cfm)

Specific heat of air = .02 Btu per (ft^3) (°F)

Heat flow through ceiling = Heat flow through roof + ventilation loss.

$$U_c\ (t_i - t_a) = U_r A_r\ (t_a - t_o) + V \times 60 \times .02\ (t_a - t_o)$$

from which

$$t_a = \frac{U_c t_i + K\ t_o}{U_c + K}$$

where $K = U_r \times \frac{A_r}{A_c} + V \times .02 \times 60$

The hourly heat loss in the ceiling is then given by

$$A_c \times U_c \times (t_i - t_a)$$

Combining the two previous equations and performing some algebra, we obtain

$$A_c \times U_c \times \left(\frac{K}{U_c + K} \right) (t_i - t_o)$$

Therefore the ceiling heat loss in Btu per year is given by

$$A_c \times K \left(\frac{U_c}{U_c + K} \right) \times \text{HDD} \times 24$$

If we assume roof slope of 4 to 12 and a .1 cfm attic ventilation:

$A_r = 1.054\ A_c$

$V = .1$

Note that $U_r = .44$[j]

---

[j] Chapter 26, Table 14 of reference [3].

∴ Ceiling heat loss per year is given by

$$\text{(B-7)} \qquad \text{load} = \frac{U_c}{.584 \text{ X } U_c} (700.8) \text{ x HDD x } 24$$

Ceiling load is evaluated for the U_c values of each insulation option. The relevant U_c are given in Table B-1.

TABLE B-1

U_c Values for Various Insulation Thicknesses[k]

Thickness (in.)	U_c
None	.65
1 1/2	.140
2	.111
3	.079
5	.050
6	.042

[k] All except the no insulation case were taken from Chapter 26, Table 15, reference [3]. The no insulation value was from Chapter 26, Table 10, reference [3].

The results of this analysis, except for the effect of the ceiling, are given in Table B-2. The tables in section 3 of the main text were derived using a computer program which added the values in Table B-2 to the proper ceiling heat load.

In addition to the heat load, the efficiency of extraction of the fuel and the efficiency of the heating system affect the yearly heating fuel consumption in Btu. The efficiency of extraction is defined as the total

TABLE B-2

Total House Heat Load Excluding the Ceiling Load

	$\frac{\text{Heat Load } (\frac{Btu}{yr})}{HDD \times 24}$	
Source	Without Storms	With Storms
Walls	168.53	168.53
Windows	198.32	98.28
Doors	16.34	11.02
Floor	129.23	129.23
Infiltration	259.20	172.80
Total	771.62	579.86

number of Btu's which are required to provide one Btu of fuel at the input to the furnace (or heating coil). This efficiency is best calculated using I-O techniques similar to those used in Appendix A.

The efficiency of the heating system is defined as the useful (in terms of heating the house) Btu's per Btu of fuel input to the furnace (or heating element). These efficiencies were empirically calculated by the Small Homes Council at the University of Illinois.[1]

TABLE B-3

Efficiencies of Different Heating Fuels

Fuel	Extraction Efficiency*	Heating Efficiency**	Overall Efficiency
Natural gas	.861	.75	.646
Oil	.839	.75	.629
Electricity	.263	1.00	.263

*Reference [4] p. 39.

**Reference [1] p. 7.

APPENDIX C

COOLING LOAD

C.1

As indicated in section 2.3, an average hourly cooling load will be utilized in the evaluation of cooling requirements as a function of insulation levels and varying geographical areas. These averages were derived by applying the following procedure for each of the eight widely separated cities and then averaging. (U values without references are the same as the heating case of Appendix B.)

Walls:

load = U x A x Equivalent Temperature Difference[a]

= .19 x 887 ft^2 x __________[a]

= 168.53 x __________[a] (Btu/hr)

Floor: Since the basement is assumed unheated, the heat gain through the floor is assumed negligible.[b]

Windows:

North load = 60 ft^2 x __________[c] (Btu/hr)

East and West load = 60 ft^2 x __________[c] (Btu/hr)

South load = 75 ft^2 x __________[c] (Btu/hr)

Infiltration:

load = gross wall area x __________[d]

= 1120 ft^2 x __________[d] (Btu/hr)

---

[a] These factors are found in Chapter 28, Table 37 of reference [3].

[b] Chapter 28, Table 37, reference [3].

[c] Factors are taken from Chapter 28, Table 38, reference [3].

[d] Factors are taken from Chapter 28, Table 40, reference [3].

Doors:

load = U x A x Equivalent Temperature Difference[b]

= 16.34 x __________[b] (Btu/hr)

Occupancy:

Heat release per occupant = 225 Btu/hr[e]

We assume 2 persons[e] per bedroom and 2 bedrooms = 4 persons

We assume[e] 1200 Btu/hr kitchen load

load = 4 x 225 + 1200 = 2100 Btu/hr

Latent heat:

We assume[e] a latent load equal to 30% of the sensible cooling load.

Ceiling:

We use the same formula for Btu/hr as in the heating load case but U_c and U_r change as does the temperature difference.

$\therefore$ hourly ceiling cooling load[f] $= 649.9 \left(\frac{U_c}{U_c + .5416} \right) \times$ Eq. Temp. Diff.

Cooling values of U_c from Table C-1 were used to evaluate the ceiling cooling load/hr.

---

[e] Chapter 28, pp. 509-510, reference [3].

[f] U_r = .40 from Chapter 26, Table 14 of reference [3]. The Equivalent Temp. Difference from Chapter 28, Table 37 of [10] was found to average 34°F.

TABLE C-1

U_c Values for Various Insulation Options[g]

Thickness (in.)	U_c
None	.46
1 1/2	.130
2	.104
3	.075
5	.048
6	.042

[g] All values except the no insulation case are from Chapter 26, Table 15 of reference [3]. The no insulation case is from Chapter 26, Table 10 of reference [3].

C.2 Overall Air Conditioning Efficiencies

We divide the overall efficiencies in two parts, fuel extraction efficiency and utilization efficiency. Fuel extraction efficiency, defined as the total number of Btu required to provide one Btu at the input to the air conditioner, is given in Table B-3.

Unlike the heating case, utilization efficiency, defined as the number of effective cooling Btu per Btu entering the air conditioner, can be greater than one. There is a wide range of attainable efficiencies depending on the type of unit, the manufacturer and certain aspects of its installation such as whether the unit is in the shade and whether it is properly sized. The question of central vs room unit also enters the discussion but it is not of overriding concern.* We have used an "average" value of 6.0/3.413 = 1.758 derived by scanning industrial data on different window air conditioners.**[11]

The overall efficiency used in this document is therefore given by

$$.263 \times 6.0/3.413 = .462$$

C.3 Cooling Season Hours for Different Geographical Locations

We give, in Table C-2, a sample of the geographical distribution of numbers of Cooling Season Hours (CSH) per year. The table is intended to give an idea of the probably maximum cooling season intensity in the continental U.S. and also to facilitate the use of this document in examples other than those considered in section 3.0.

---

*According to Mr. D. E. Brotherson of the Small Homes Council of the University of Illinois, under some conditions, room air conditioners are more efficient than central air. Under different conditions, the reverse is true.

**Reference [11] gives efficiencies in units of Btu/watt-hr. The 3.413 is simply the conversion factor needed to obtain the proper units.

TABLE C-2

Estimated Annual Hours of Operation for Properly Sized Equipment in Typical Cities During Normal Cooling Season (average indoor temperature of 80°F)

Atlanta	750
Boston	200
Chicago	400
Cleveland	450
Dallas	1400
Fresno	900
Jacksonville, Fla.	1600
Minneapolis	350
New Orleans	1500
New York	350
St. Louis	1000
Washington, D.C.	800

Source: Chapter 17, Table 2, reference [5].

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